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Two New Planetary Nebulae Discovered in a Galaxy Search in the Southern Milky Way

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Abstract. Spectroscopic observations have been carried out for eleven objects believed to be planetary nebulae on the basis of their optical appearance. They were discovered in an ongoing deep search for galaxies in the Southern Milky Way (Kraan-Korteweg & Woudt 1994). The objects were observed with the 1.9m telescope of the South African Astronomical Observatory during our program for obtaining redshifts of obscured galaxies in the "Zone of Avoidance". Of the eleven objects, three proved too faint for a definite classification, four were galaxies with radial velocities between v=3920 km/s and v=14758 km/s, but four were confirmed as planetary nebulae (PNE). Their relative line strengths and radial velocities have been determined. The PNE are on average fairly large ($23''-30''$). Two of them (PNG 298.3+06.7 and PNG 323.6-04.5) were previously unknown; for these we show Hα and [O III] images.

Key words: surveys – planetary nebulae: general – planetary nebulae: individual: PNG 298.3+06.7 and PNG 316-04.5 – galaxies: redshifts

1. Introduction

The foreground absorption of our Galaxy obscures about 25% of the extragalactic sky. In order to narrow this "Zone of Avoidance", we have been searching the film copies of the ESO/SERC IIIaJ survey in the southern Milky Way for partially obscured galaxies. Using a 50 x magnifying viewer, we have identified all galaxies and galaxy candidates to a lower diameter limit of D=0.′2, and − depending on their surface brightness − to a magnitude limit of about $B_J \approx 19.^m0$-$19.^m5$. To date, over 10,000 previously uncatalogued galaxies have been identified in the area $266° \lesssim \ell \lesssim 340°, |b| \lesssim \pm 10°$. For further details the reader is referred to Kraan-Korteweg, 1989, Kraan-Korteweg & Woudt 1994, and references therein.

In the course of this deep search we have come across a number of extended objects having sharp edges that suggested their being PNE rather than external galaxies. In section 2, the optical properties of these 11 prospective PNE are described. These objects were observed spectroscopically with the 1.9m telescope of the SAAO during our redshift observations of galaxies in the Zone of Avoidance (Kraan-Korteweg et al. 1994, 1995, Kraan-Korteweg, Fairall & Balkowksi, 1995). The spectroscopic observations are described in section 3. Four of the eleven objects are confirmed as PNE. The resulting spectra are displayed and their relative line strengths discussed. Two PNE were previously unknown. In section 4, the [O III] and Hα images obtained at the 90cm Dutch telescope of the European Southern Observatory (ESO) of these PNE are displayed, followed by a discussion of the two new PNE in the last section.

2. The planetary nebula candidates

The 11 prospective PNE are shown in Figure 1.

As mentioned above, they were classified as PN-candidates based on their optical appearance on the film copies of the ESO/SERC IIIaJ sky survey. These extended objects were not believed to be galaxies because of their sharp edges − too sharp for the characteristic morphology of external galaxies. Furthermore half of the objects reveal a distinct central core. Two of the objects (3 and 9) display a high surface brightness.

The positions and other parameters of the objects are listed in Table 1. The entries in Table 1 are as follows:
Column 1: Running number, corresponding to the images displayed in Figure 1.
Column 2: Identification of the galaxy. E denotes the identification in the ESO-Uppsala Survey (Lauberts, 1982),

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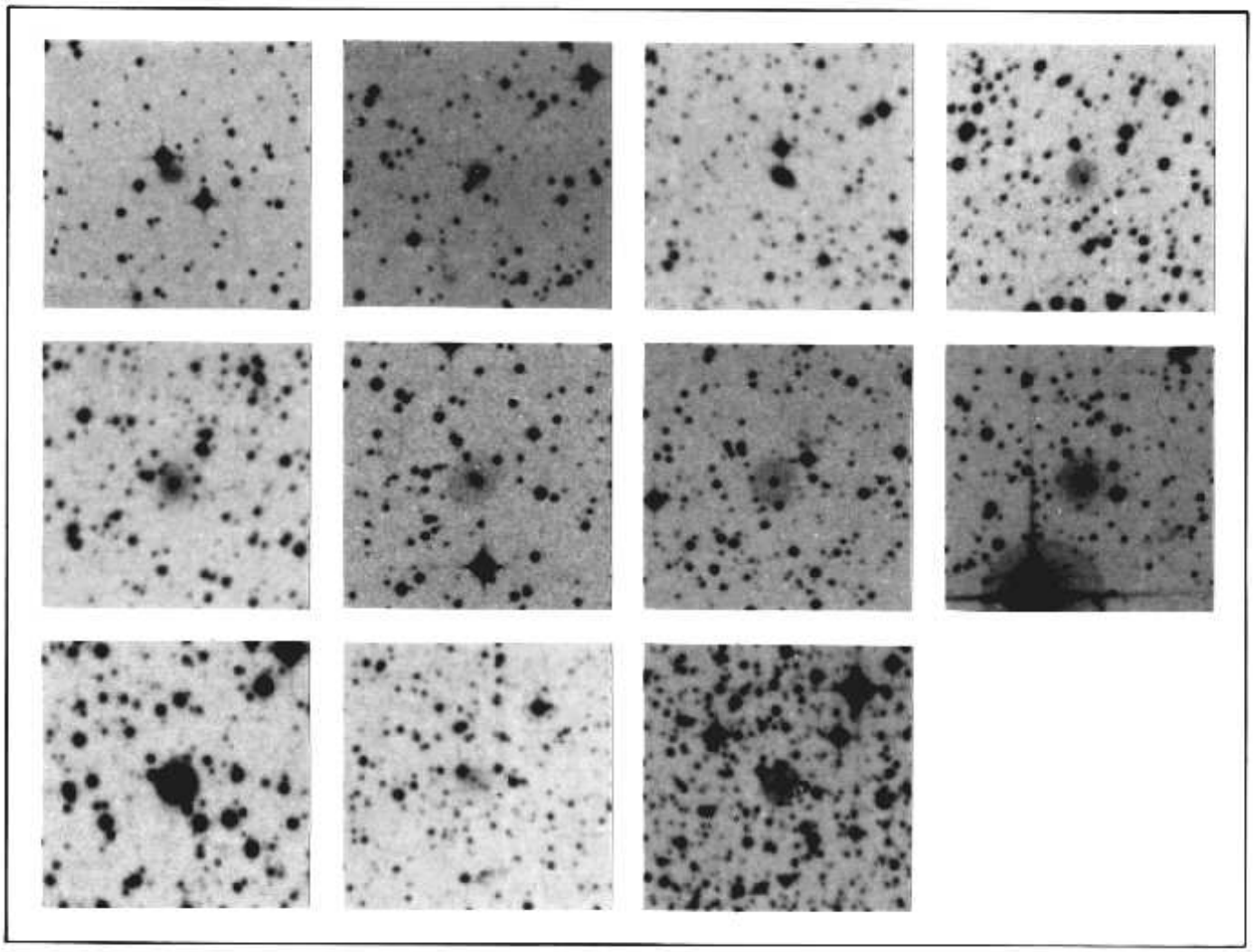

Fig. 1. Images of the prospective PN-candidates as seen on the film copies of the ESO/SERC IIIaJ survey during the galaxy search. The images are enlarged by a factor of 20 and are 2′.2 x 2′.2. North is up, east is left. The images are ordered from left to right, top to bottom according to the sequence in Table 1.

RKK refers to the catalogue of galaxies in the southern Milky Way in the Hydra/Antlia extension (Kraan-Korteweg 1996, henceforth RKK96), and WKK to its extension towards the Great Attractor region (Woudt and Kraan-Korteweg, 1996 [WKK96]). RKK-P1 refers to a separate listing of objects identified in RKK96 which most likely are PNE, not galaxies. The asterix indicates that the object has an entry in the IRAS PSC (cf. Table 2).

Column 3 and 4: Right Ascension and Declination (epoch 1950.0). The positions were measured with the measuring machine Optronics at the ESO in Garching and have an accuracy of about 1 arcsec.

Column 5 and 6: Galactic longitude ℓ and latitude b.

Column 7, 8 and 9: The field of the ESO/SERC survey on which the object was measured and the x and y offset in mm from the center of that field.

Column 10: Large and small diameter (in arcsec). The diameters are measured to an approximate isophote of 24.5 mag arcsec^{-2} and have a scatter of $\sigma \approx 4''$.

Column 11: Apparent magnitude B_J. The magnitudes are estimates from the IIIaJ film copies of the ESO/SRC Survey based on the above given diameters and an estimate of the average surface brightness. A preliminary analysis of this data for the galaxy survey finds a linear relation from the brightest to the faintest magnitudes ($B_J \approx 19\overset{m}{.}5$) with a scatter of only $\sigma \approx 0\overset{m}{.}5$.

Column 12: Object status after spectroscopy and/or heliocentric velocity (cf. next section).

3. Spectroscopic Observations

The spectroscopic observations of the 11 prospective planetary nebulae were made during observing runs in March 1991, 1993 and April 1994 at the South African Astro-

Table 1. PN-candidates observed spectroscopically at the SAAO

RN	Identification	RA 1950.0	Dec 1950.0	gal. ℓ	gal. b	SRC	X (mm)	Y (mm)	Dxd ($''$)	B_J mag	Status
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
1	RKK 0008	$8^h31^m19\overset{s}{.}7$	-55°55′40″	272.17	-9.58	165	-127.8	-52.8	13x13	18.2	gal. at $v = 4219$km/s
2	RKK-P1	$8^h39^m10\overset{s}{.}1$	-55°42′ 2″	272.65	-8.56	165	-69.3	-38.1	16x12	18.2	too faint, no em. det.
3	E166-P18*	$9^h29^m\ 8\overset{s}{.}8$	-52°56′43″	275.52	-1.33	166	65.5	109.4	23x15	16.7	PN confirmed
4	RKK 1833	$9^h56^m58\overset{s}{.}3$	-63°41′21″	285.26	-7.17	92	-115.2	68.4	20x20	17.5	gal. at $v = 11522$km/s
5	RKK 2432	$10^h21^m16\overset{s}{.}6$	-65°31′46″	288.47	-7.17	92	27.3	-25.9	26x19	17.0	gal. at $v = 14758$km/s
6	RKK 2450	$10^h21^m51\overset{s}{.}4$	-49°31′ 7″	279.97	6.41	214	-71.7	24.2	34x28	16.4	gal. at $v = 3920$km/s
7	WKK171-090	$12^h15^m51\overset{s}{.}7$	-55°37′25″	298.30	6.67	171	73.7	-33.9	28x28	16.9	**new PN**
8	WKK171-052	$12^h19^m\ 5\overset{s}{.}0$	-54° 6′24″	298.58	8.24	171	101.9	46.3	35x26	16.9	too faint, no em. det.
9	E131-P01	$12^h21^m\ 8\overset{s}{.}4$	-59°56′34″	299.51	2.47	131	-124.9	.1	30x28	16.1	PN confirmed
10	WKK172-334	$12^h31^m\ 2\overset{s}{.}9$	-56°22′10″	300.50	6.14	172	-60.8	-73.4	16x15	18.2	too faint, no em. det.
11	WKK136-337*	$15^h46^m18\overset{s}{.}4$	-59°49′44″	323.63	-4.51	136	-28.2	10.5	26x24	17.0	**new PN**

nomical Observatory (SAAO) at Sutherland. The 1.9m Radcliffe reflector with "Unit" spectrograph and reticon photon-counting detector was used. The dispersion was approximately 2.8Å per pixel. The reduction procedures are described in detail in Kraan-Korteweg, Fairall & Balkowski (1995).

Three of the 11 objects (2, 8, and 10) were too faint, their surface brightness too low, for a definite conclusion to be made about their nature. No emission was detected. Spectroscopy of the other 8 objects proved four (1, 4, 5, and 6) to be galaxies despite their optical appearance. Their redshifts are given in the last column of Table 1. The remaining four objects (3, 7, 9 and 11) were confirmed as PNE. A cross-identification with the Strasbourg-ESO Catalogue of Galactic Planetary Nebulae (Acker et al. 1992) indicates that the two planetary nebulae WKK171-090 and WKK136-337 were previously unknown. In accordance with the astronomical nomenclature convention for PN by their galactic coordinates (Acker at al. 1992), they are forthwith called PNG 298.3+06.7 and PNG 323.6-04.5

The spectra of the four PNE are illustrated in Figure 2. The identified emission lines are marked. The spectral line fluxes of the PN with the higher surface brightness on the plates, the previously known E166-P18 = PNG 275.5-01.3 and E131-P01 = PNG 299.5+02.5, are higher compared to the two previously unknown PNE. For the planetary PNG 323.6-04.5, the Balmer line is relatively weak. Some coincidence is found at the lines NeIII, [O III](4363Å) and HeII, but they are not believed to be real.

Of the 4 spectroscopically observed PNE, only PNG 275.5-01.3 and PNG 323.6-04.5 are listed in the IRAS PSC. Their respective fluxes are given in Table 2.

3.1. Relative line strengths and radial velocities of the 4 planetary nebulae

The use of narrow slits and the general characteristics of the spectrograph do not permit absolute calibration of the intensity scale. The observation of spectrophotometric standard stars has enabled us to measure the relative instrumental response and the spectra have been suitably corrected. Relative instrumental calibration was done by observing a spectrophotometric standard star – in this case LTT 7379. PNG 275.5-01.3 was observed in March 1991. Unfortunately, no spectrophotometric standard star was observed at that time due to adverse weather conditions and we therefore have no accurate way to bridge the Hα region response to the Hβ region response for this planetary. A rough estimate was made from the other observing runs, with sufficient accuracy to establish that there is a steep Balmer decrement, and thus a large amount of reddening.

The "Unit" Spectrograph with Reticon Photon Counting System is generally used for radial velocity work and is not an ideal instrument for measuring line strengths. However, we observed the planetary nebula NGC 3132 = PNG 272.1+12.3 at RA=$10^h04^m55^s$, Dec=$-40°11'29''$ with known line strengths as a standard. This PN has a similar diameter compared to the PNE in our sample (D=$30''$). The results for the 4 PNE and our "standard PN" are summarized in Table 3.

The header line lists the identified emission lines with their respective wavelengths in Ångstrøm. The first column lists the name of the PNE and source: for the 2 previously known PNE and the standard, the data as given in the Strasbourg-ESO catalogue of Galactic Planetary Nebulae (Acker et al. 1992) are listed (identified by "Acker" in the first column) next to our results (identified with "SAAO"). This allows an assessment of the accuracy of the observational procedures for extracting relative line strenghts. Blow-up plots were used to measure the area under the lines and establish the linestrengths. In conformance to the Acker et al. catalogue, the fluxes are expressed relative to an Hβ-line intensity of 100. The second to last column lists the logarithm of the absolute flux of the Hβ line (in mW m^{-2}) for the standard PN and the 2 previously known PNE. Radial velocities were derived from the stronger emission lines. The centroids of the emission lines were again determined from the blow-up plots. The resulting values are entered in a second line in Table

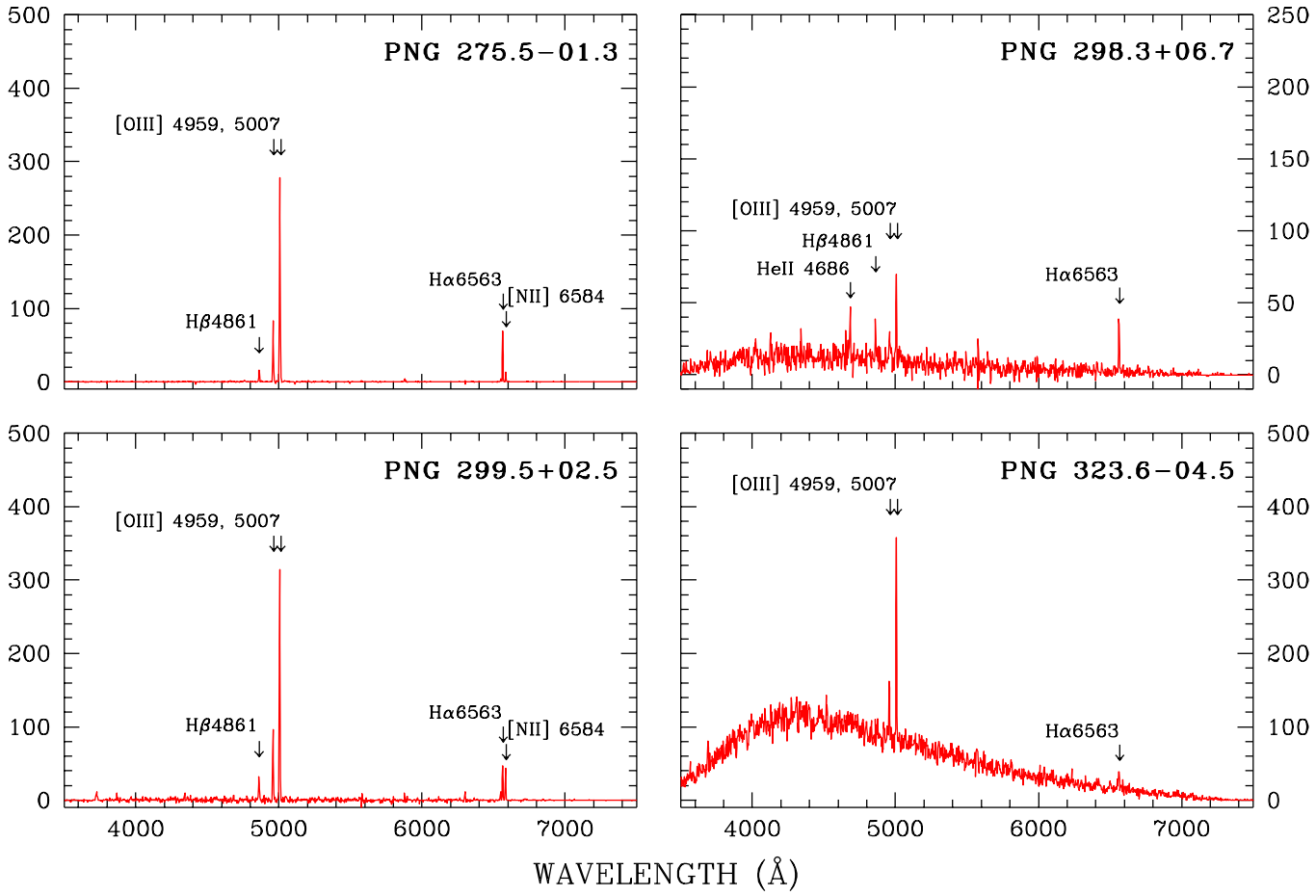

Fig. 2. Spectra of the four confirmed PNE obtained with the 1.9m telescope of the SAAO.

2 at the respective wavelengths. The last columns lists the mean radial velocity of the 4 PNE.

4. CCD-Imaging of the 2 new planetary nebulae PNG 298.3+06.7 and PNG 323.6-04.5

Shortly after the spectroscopic identification of the 2 new PNE, CCD images were taken of PNG 298.3+06.7 and PNG 323.6-04.5 in both Hα and [O III] using the Dutch 0.9m telescope of the European Southern Observatory. This telescope is equipped with a TEK512 CCD camera, giving a field of view of $3\farcm8$x$3\farcm8$ and a pixelsize of $0\farcs44$/pixel.

The resulting CCD images are shown in figure 3. The top panels illustrate PNG 298.3+06.7: the exposure time for the Hα and the [O III] images were 1200 sec and 1800 sec respectively. The basic reductions such as bias subtraction and flat fielding were done within the MIDAS image reduction package.

The bottom panels show PNG 323.6-04.5. The same Hα and [O III] filters were used for these observation. In this case however, both images have an exposure time of 600 seconds.

Due to non-photometric weather conditions these images are not flux calibrated. As discussed in the next section, they do, however, give a fair impression of the optical morphology and show the similarity in appearance between both new PNE.

5. Discussion of the new planetary nebulae

These new optically discovered PNE appear very spherical. They are of rather faint surface brightness, which is probably why they have gone undetected.

Both new PNE are probably closer than 8 kpc: because of the concentration of PNE towards the galactic bulge, the distribution of angular diameters of PNE has a strong peak between 4 and 12 arcsecs – although nearer nebulae with angular diameters up to 2 arcminutes have been observed. PNG 298.3+06.7 and PNG 323.6-04.5 both have an angular size of $20\farcs3$ and are among the larger PNE. Most bulge planetary nebulae with a distance of typically 6 - 10 kpc have diameters below $10''$. Hence, the 2 newly uncovered PNE are likely to be closer than the Galactic center distance of 8 kpc.

Table 3. Emission line strengths for the four confirmed PN and the calibrator NGC 3132=PNG 272.1+12.3

PN	[OII] 3727	[NeIII] 3868	Hγ 4340	[OIII] 4363	HeII 4686	Hβ 4861	[OIII] 4959	[OIII] 5007	HeI 5876	[NII] 6548	Hα 6563	[NII] 6584	[SII] 6717	[SII] 6731	lg I(Hβ)	Vel.
PNG 272.1+12.3 (Acker)				4	5	100		1021	14		319	393	32	32	-10.45	-10± 3
PNG 272.1+12.3 (SAAO)	321	76	30	4		100	255	939		279	416	966				
Radial velocity	-53		-48			-32	-7	-13			+5	+28				-15±40
PNG 275.5-01.3 (Acker)				-	-	100		1844	42		1496	339	12	23	-13.00	
PNG 275.5-01.3 (SAAO)			30			100	427	1568		279	1000:	188:				
Radial velocity						+37	+2	+2			+29					+17±16
PNG 298.3+06.7 (SAAO)			63		122	100	93	216	40		412	50				
Radial velocity			-35			-37	(-6)	-48			-32					-38± 6
PNG 299.5+02.5 (Acker)				-	-	100		807	-		610	486	83	82	-12.60	-10±12
PNG 299.5+02.5 (SAAO)						100	271	897		87	403	352				
Radial velocity						-41	-10	-16			+7	-25				-17±16
PNG 323.6-04.5 (SAAO)						100[(a)]	788	2538			1031	352				
Radial velocity						-9	-87	-38			-37					-41±25[(b)]

[(a)] Hβ is only marginally present and the relative line strengths should be regarded as tentative only

[(b)] higher weight was given to the velocity determined from [O iii] λ5007, the stronger isolated line in the spectrum

Fig. 3. Images of the PNE PNG 298.3+06.7 (top panels) and PNG 323.6-04.5 (bottom panels) obtained with the 0.9m Dutch telescope at la Silla, ESO. Left panel: Hα (ESO filter 387), right panel: [O III] (ESO filter 688). Note that North is up and East is right.

Though these nebulae look very similar there is a striking difference between them. The central star of PNG 298.3+06.7 is only a few times brighter compared to the mean of the nebular brightness, while the star at the center of PNG 323.6-04.5 is more than ten times brighter than the nebula. The central star of PNG 298.3+06.7 clearly is pointlike, while the central part of PNG 323.6-04.5 might be slightly resolved – but this needs to be confirmed. The central star of PNG 323.6-04.5 is very bright and the limb of the nebula more defined than PNG 298.3+06.7.

The dust temperatures of the PNE detected by IRAS were calculated according to the formalism given in Van de Steene & Pottasch (1993, 1995). For PNG 323.6-04.5, the dust temperature is found to be 86 K. This low dust temperature together with the very low far IR flux of $1.1{\cdot}10^{-13}$ W m^{-2} (cf. Table 2) is indicative of an evolved nebula with little dust. The observed Hα/Hβ ratio, as compared to the recombination value of 2.85 (Aller, 1984), results in a logarithmic extinction at Hβ of:
c(Hβ) = 3.096 log(Hα / (Hβ / 2.85))
corresponding to a visual extinction of A_V = 2.1 c(Hβ). The extinction values determined from the Balmer lines by Tylenda et al. (1992) from better spectra are 0.16, 2.2 and 1.0 for PNG 272.1+12.3, PNG 275.5-01.3 and PNG 299.5+02.4 compared to 0.5, 1.7 and 0.5, the values determined from the SAAO spectra. The logarithmic extinction of the new PNE are 0.5 for PNG 298+06.7 and 1.7 for PNG 323-04.5, where the higher extinction for PNG 323-04.5 is evident already in the images.

The flux values were corrected for interstellar extinction using the literature values and the galactic extinction law of Seaton (1979).

The photon energy distribution determines the degree of excitation in the nebula reflected by the excitation class (E.C.). The excitation class was calculated using the extinction corrected line fluxes, according to the scheme by Dopita & Meatheringham (1991):
E.C. = 5.54 ($F_{\lambda4686}/F_{H\beta}$ + 0.78) for 5.0 ≤ E.C.
E.C. = 0.45 ($F_{\lambda5007}/F_{H\beta}$) for 0.0 ≤ E.C. ≤ 5
This definition is to some extent sensitive to the chemical abundances of helium and of oxygen, and also on the ionization parameter. To estimate the stellar temperature (T_{eff}), we used the correlation between E.C. and T_{eff} (Dopita & Meatheringham, 1991). We find E.C.= 4.1 and T∗ =80,000 K for PNG 272.1+12.3. Preite-Martinez et al. (1989, 1991) determined an E.C.= 6 and a T_{eff}=99,400 K using the energy balance method. For PNG 275.5-01.3, the excitation class determined from the [O III] line is 5.9. This translates to T_{eff}>100,000 K. In the latter case one would, however, expect to see He II which is not observed. Preite-Maritnez et al. determined E.C.=5 and an energy balance T_{eff}=81,600 K. For PNG 299.5+02.4 we determined E.C.=3.7 corresponding to T_{eff}=75,000 K, while Preite-Martinez et al. determined E.C.=5 and T_{eff}=71,800 K.

The blue stellar continuum of the white dwarf is visible in both spectra of the new PNE. According to what we see in the images the stellar continuum appears stronger for PNG 323.6-04.5 than for PNG 298.3+06.7.

For PNG 298.3+06.7 the extinction-corrected [O III]λ5007 line (208) is a bit weaker than Hα, indicative of a relatively low excitation. But the He IIλ4686 line seems exceptionally strong! This line is usually much weaker than Hβ – even in PNE which are overabundant in helium. It could, of course, be that the hydrogen lines are exceptionally weak and that this PN belongs to the class of hydrogen deficient PNE, but this would indicate a very high excitation nebula. For PNG 323.6-04.5 the [O III] line is very strong. It is therefore peculiar that no He II is apparent in this high excitation nebula unless, of course, Hα is very weak and this is also a hydrogen deficient nebula. Future observations will tell. The present information is insufficient to determine either electron temperature or density for the new PNE.

Our galaxy search is still ongoing and further prospective PNE have been discovered meanwhile. We will report on those as soon as we have follow-up observations.

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Table 2. Planetary Nebulae in the IRAS PSC

RN	Identification	IRAS-name	IRAS-flux				flux qual.
			f_{12}	f_{25}	f_{60}	f_{100}	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
3	PNG 275.5-01.3	09291-5256	0.25L	1.41	2.94	5.74	-CCD
11	PNG 323.6-04.5	15463-5949	0.37L	0.34	1.32	20.04L	-BB-

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